3GPP Mobile Telecommunications Technology on the Moon

National Aeronautics and Space Administration

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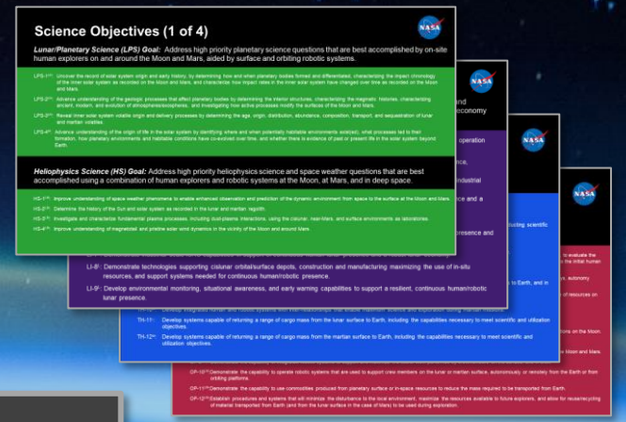
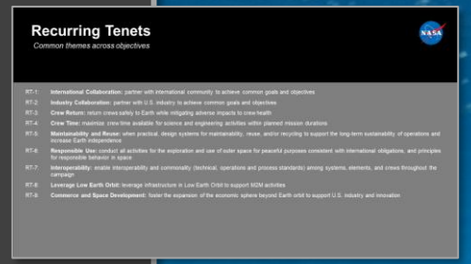
NASA's Moon-to-Mars Blueprint Objectives

- **Latest released in September 2022**
- **63 Top-Level Objectives across 10 Top-Level Goals**
  - 26 Science (6 Goals) – Led by SMD
  - 13 Infrastructure (2 Goals) – Led by STMD
  - 12 Transportation & Habitation (1 Goal) – Led by ESDMD
  - 12 Operations (1 Goal) – Led by SOMD
- **9 Recurring Tenets (RT)**
  - Common themes across objectives



RT-1: **International Collaboration**
RT-2: **Industry Collaboration**
RT-3: **Crew Return**
RT-4: **Crew Time**
RT-5: **Maintainability and Reuse**
RT-6: **Responsible Use**
RT-7: **Interoperability**
RT-8: **Leverage Low Earth Orbit**
RT-9: **Commerce and Space Development**



Infrastructure Objectives Relevant to Comm & Nav

Lunar Infrastructure (LI) Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

LI-2^{L}: Develop a lunar surface, orbital, and Moon-to-Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.

LI-3^{L}: Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.

Mars Infrastructure (MI) Goal: Create essential infrastructure to support initial human Mars exploration campaign.

MI-2^{M}: Develop Mars surface, orbital, and Mars-to-Earth communications to support an initial human Mars exploration campaign.

MI-3^{M}: Develop Mars position, navigation and timing capabilities to support an initial human Mars exploration campaign.

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

3GPP and NASA

Over the past 10 years NASA has explicitly used the *mobile smartphone experience* as a descriptive goal for the evolution of the NASA communication networks and services.

NASA is embarking on an initiative to commercialize its near-Earth communication and navigation capabilities/services.

3rd Generation Partnership Project (3GPP) is an umbrella organization known for the development and maintenance of mobile telecommunications standards.

NASA wants to explore the applicability of 3GPP standards:

- In the Earth proximity region
- On the lunar surface

Can NASA use 3GPP standards “as is” or with small modifications officially made by 3GPP?

4G / 5G in the Lunar Environment

NASA has been instrumental behind a Consultative Committee for Space Data Systems (CCSDS) Working Group promoting the use of 4G / LTE, along with other wireless technologies, for surface communications

- CCSDS 883.0-R-1 (2022) to recommend interoperable LTE configurations for high-data-rate proximity wireless networks

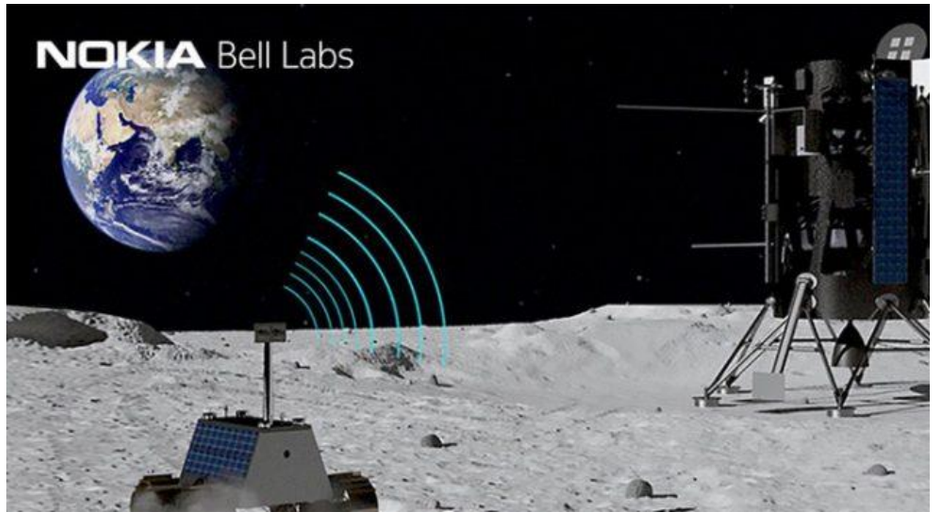
NASA has also internally been investigating the use of 4G / LTE technologies in the lunar environment:

- LunarLiTES: A SCaN effort to emulate and characterize LTE networks within NASA's lunar communications architecture
- Advanced Exploration Systems / Artemis program:
  - Analysis of lunar surface wireless needs against 3GPP capabilities
  - Evaluation of private LTE systems against notional EVA requirements, building toward outdoor field testing

NASA awarded a Tipping Point contract to Nokia to demonstrate space rated 4G/LTE hardware near the Lunar South Pole

- Base station on lander, deployable rover with user equipment (UE)
- Demonstration will support detail analysis into 4G/LTE performance

NASA is also interested in directly using 5G from the lunar surface to a lunar relay satellite



STMD Tipping Point was awarded to Nokia and Intuitive Machines for a 4G/LTE demonstration on the Moon

While our focus to date has been on 4G / LTE, we think any future operational lunar network will be 5G and beyond

Current 10 km Surface Wireless Gap

Current Artemis Surface Communications Architecture

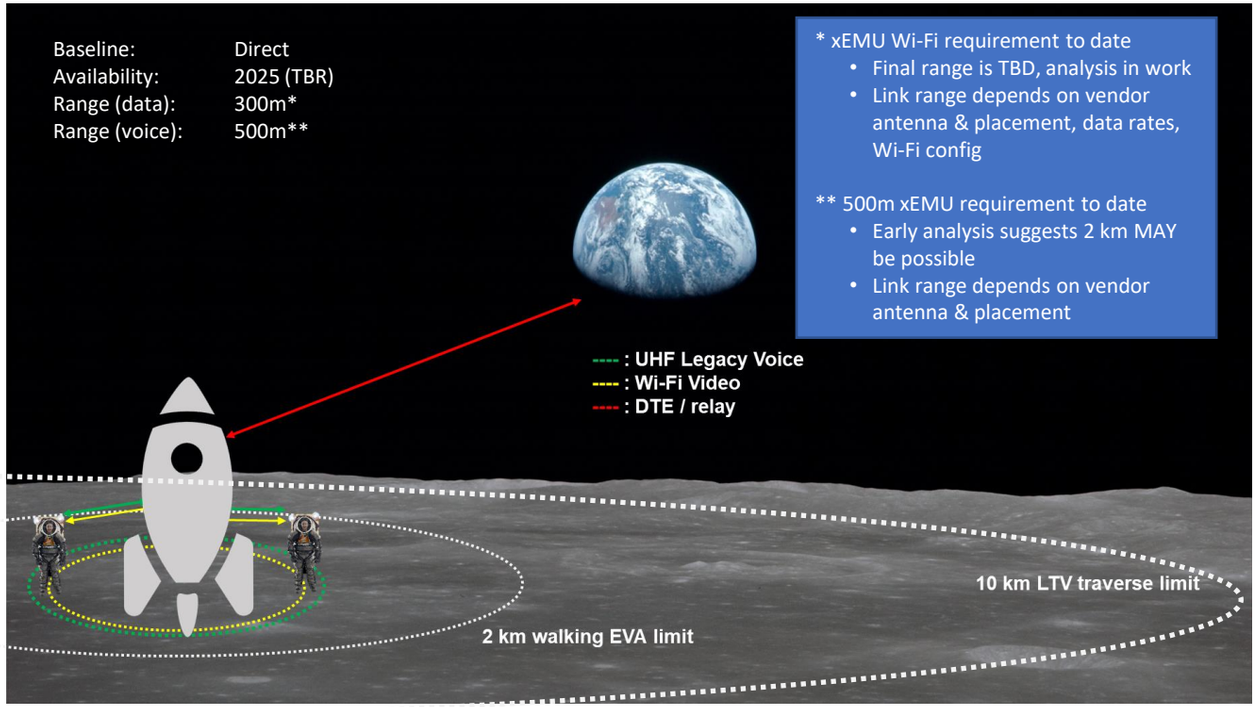
- WiFi for Data and UHF for Voice
- Range of 300 m to 500 m depends on vendor antenna choice, placement, max radiated power, etc.

Current Artemis surface communications architecture ***does NOT meet*** the LTV 10 km traverse limit requirement

- Point-to-point links scale poorly, demanding additional capacity and management effort

3GPP/5G (or greater) equipment preferred for operational deployment

- Supports high throughput while mobile
- Provides Quality of Service (QoS) provisions for different kinds of traffic, e.g., mission critical voice vs. science video, etc.
- Proven technology in multipath environment
- Scales capability as assets are added
- Interoperable with international partners
- Efficient and responsible use of spectrum resources
- Leverages terrestrial commercial advancements for affordability
  - Future PNT and Sidelink/V2X functions of great interest.
  - Non-Terrestrial-Networking (NTN) could be employed by future Lunar relays to provide ubiquitous Lunar comm



Current Artemis Surface Communications Architecture

In the 21st century, NASA does not have to invent its own special purpose surface wireless communications system

Lunar Surface Communications via 3GPP

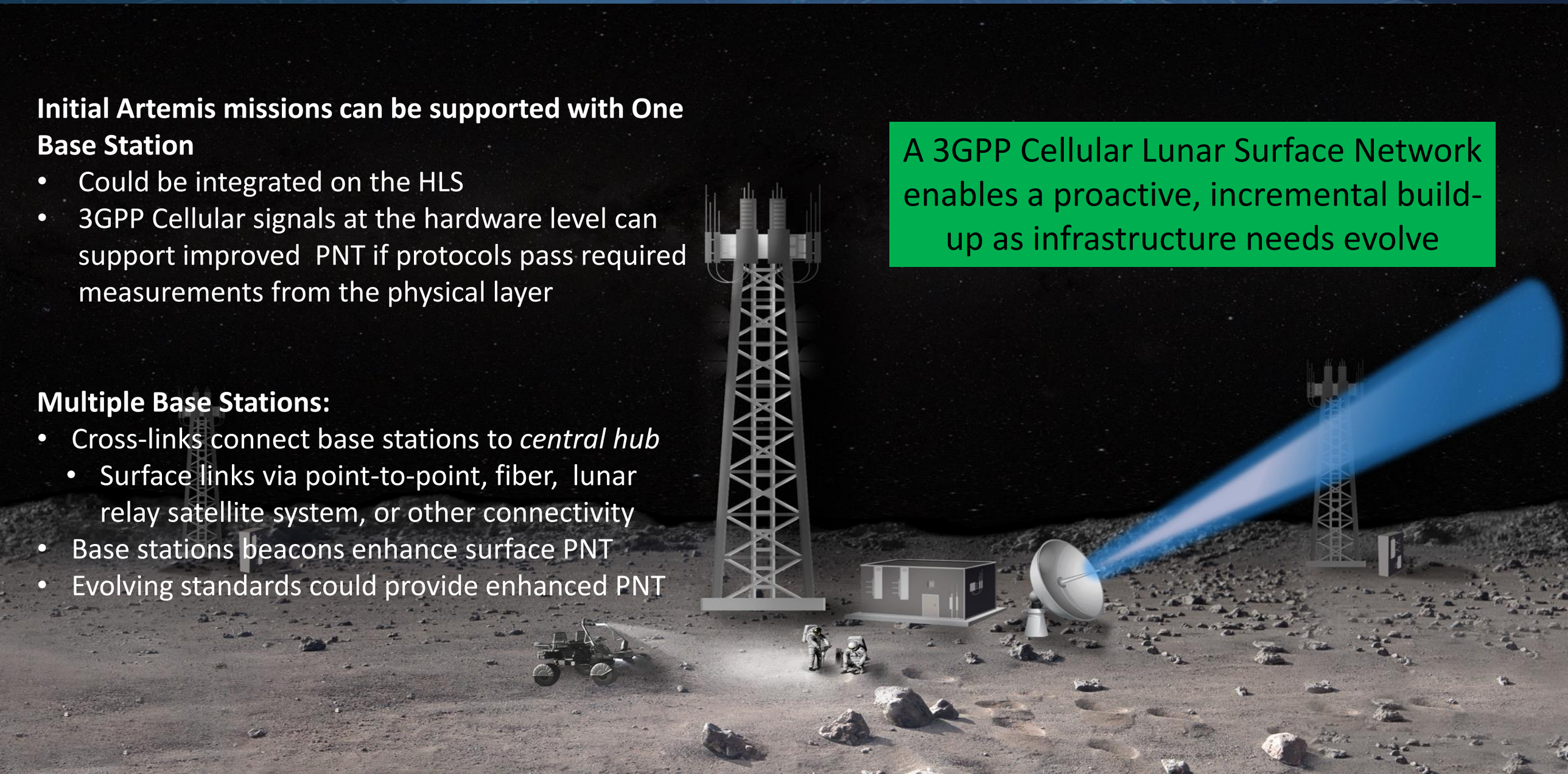
Initial Artemis missions can be supported with One Base Station

- Could be integrated on the HLS
- 3GPP Cellular signals at the hardware level can support improved PNT if protocols pass required measurements from the physical layer

Multiple Base Stations:

- Cross-links connect base stations to *central hub*
  - Surface links via point-to-point, fiber, lunar relay satellite system, or other connectivity
- Base stations beacons enhance surface PNT
- Evolving standards could provide enhanced PNT

A 3GPP Cellular Lunar Surface Network enables a proactive, incremental build-up as infrastructure needs evolve



Tall Tower Efforts Relevant to a 3GPP Effort

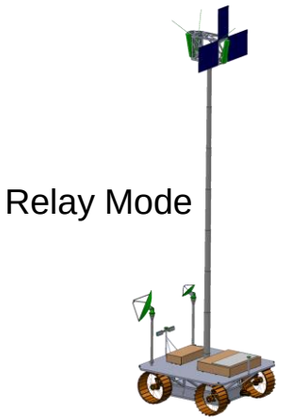
NASA's Space Technology Mission Directorate (STMD) has 3 companies under contract to build vertical solar array tower prototypes and perform environmental testing

- Greater than 50m height for solar arrays can reduce lunar night to just 2 days and significantly reduces battery mass

NASA's Space Communications and Navigation (SCaN) program is studying the concept of a 10-meter deployable communications and navigation tower on a rover that can be transported over the lunar surface.

- 10-meters would limit surface 3GPP coverage to about ~5 Km
- 10-meter tower would be easier to independently land on the surface and transport

NASA's Tall Lunar Tower (TLT) In-Space Assembly (ISA) team aims to design, model, fabricate, autonomously assemble, and characterize a TLT engineering development unit (EDU). Cross-cutting truss assembly technology will be developed enabling construction of infrastructure in the lunar environment.



Relay Mode

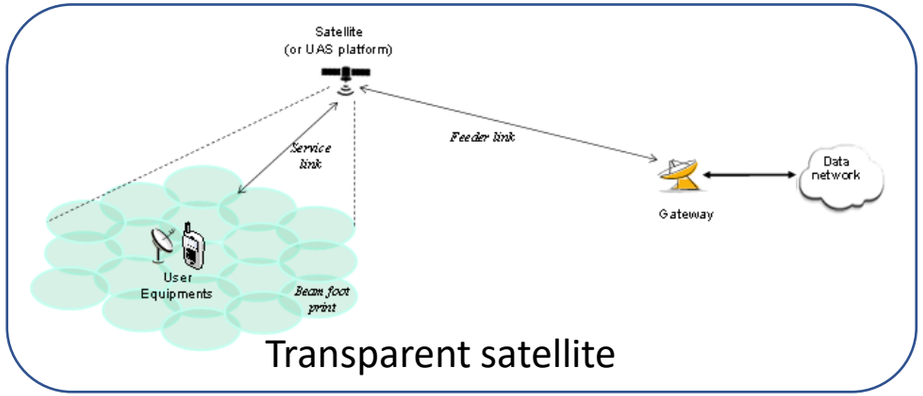
Roving Mode

Possible 3GPP Support from Lunar Relay Satellites

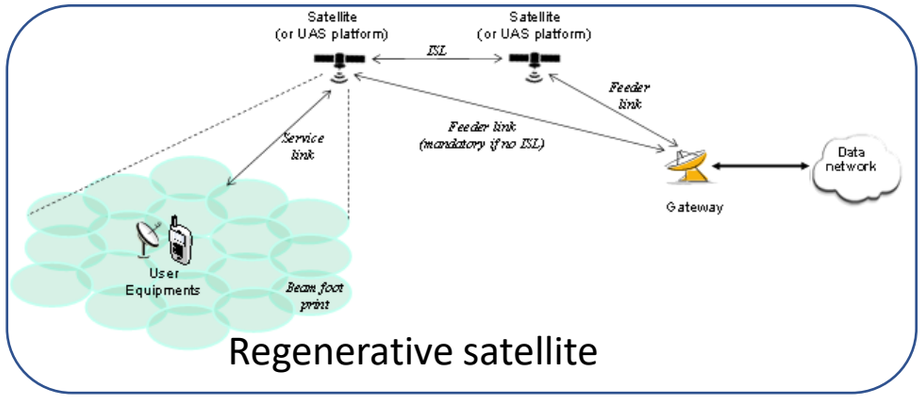
The 3GPP Organization is Developing Non-Terrestrial Networking Concepts and Designs:

- Transparent satellite
  - Core Network and eNB on Earth; Satellite acts as a bent pipe to/from UEs located on Earth
- Regenerative satellite
  - Core Network and UEs on Earth, eNB on the satellite
- Regenerative Satellite with inter-satellite link
  - Core Network on Earth, eNBs in satellites, UEs on Earth

Replace "Earth" with "Lunar" and these architectures may be useful to augment surface comms on the Moon.



Transparent satellite



Regenerative satellite

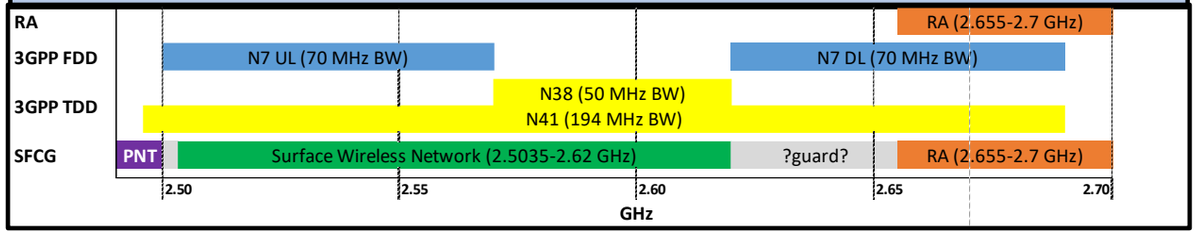
NASA needs to research these Non-Terrestrial Network (NTN) concepts and determine if they can be used on Lunar Relay Satellites to augment Lunar Surface Communications:

- Seamlessly tie to the surface network
- Surface User Equipment routes via relay satellite or base station

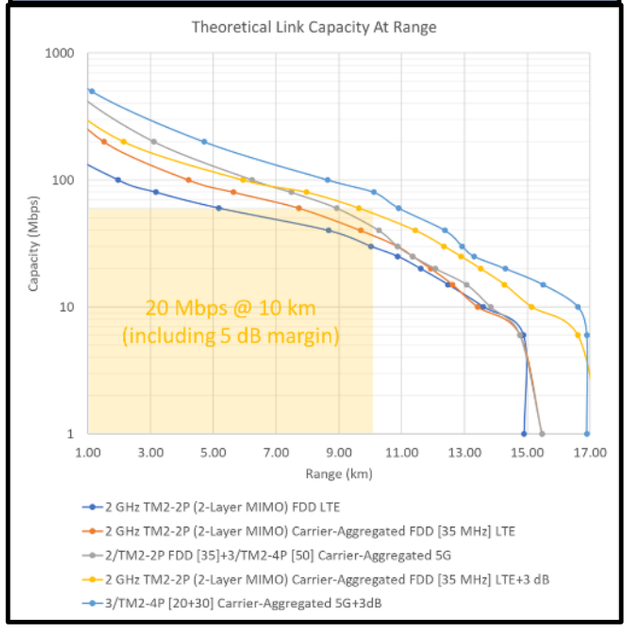
Spectrum & Implementation Options

- NASA is teaming with university experts to study and guide a near-term and long-term implementation approach.
  - University of Colorado Boulder, Simon Fraser University, and the Johns Hopkins University Applied Physics Laboratory
  - Expertise in establishing 3GPP networks in remote locations that emulate the lunar environment
  - Extensive laboratory equipment and testing capability

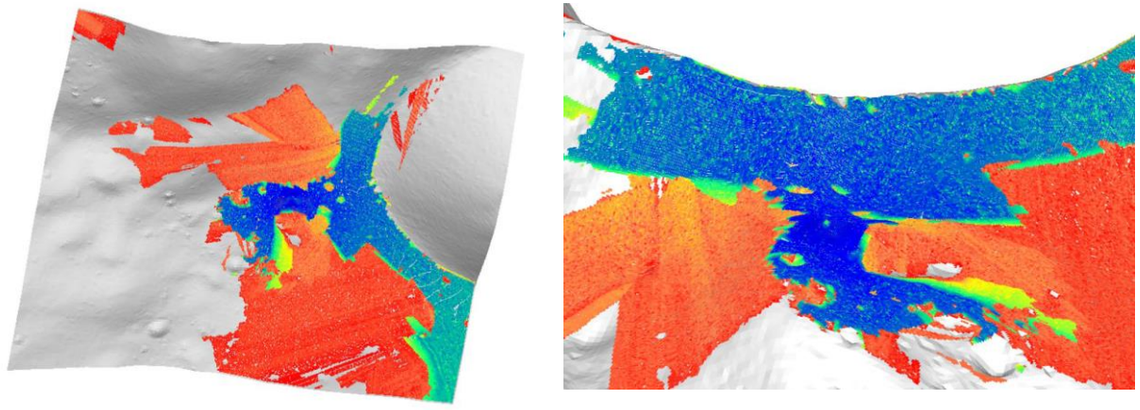
Initial spectrum requests through the SFCG and ITU



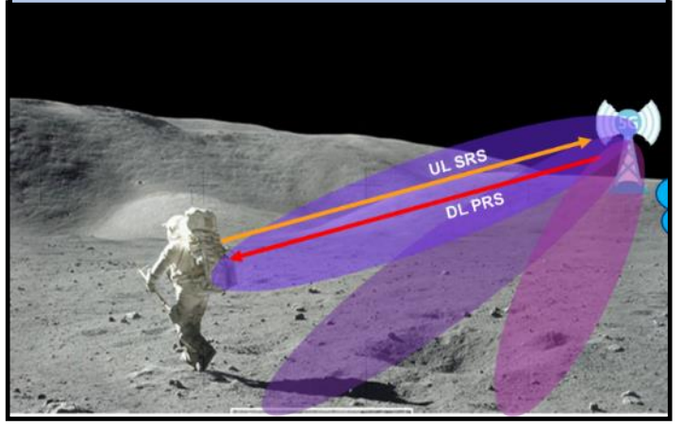
General payload equipment options for Artemis



Initial coverage map analyses



PNT capabilities to enhance LunaNet navigation solutions



Summary of SFCG 32-2R4 recommended bands for 3GPP use

Reference #	3GPP Band	Frequencies (GHz)
SFCG B1	N7 / 38 / 41	2.5035 – 2.6550
SFCG B2	N48 / 77 / 78	3.5000 – 3.8000
SFCG B3	N46	5.1500 – 5.8350
SFCG B4	N47	5.8550 – 5.9250
SFCG B5	N258	25.2500 – 25.5000
SFCG B6	N257 / 258	27.2250 – 27.5000
SFCG B7	N257 / 261	27.5000 – 28.3500

SFCG Reference Numbers used in the paper for simplicity

- Overall, this Space Frequency Coordination Group recommendation has a very large amount of total bandwidth. However, SFCG B3 is shared use with Wi-Fi, and SFCG B5/6/7 are not expected for use until larger networks and more complex use cases demand very high rate user links and multicellular backhaul crosslinks.
- The SFCG frequency ranges do not exactly match the 3GPP band frequency ranges, and therefore will have a reduced number of channels within the recommended bands.

Gap Closure: From 4G Tipping Point to Artemis V

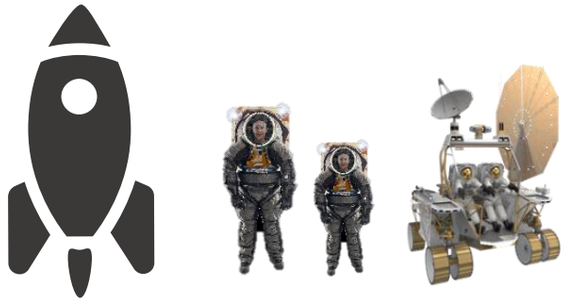
Lunar LTE Tipping Point

- Robotic-class
- Single band
- Older 3GPP release (4G)

Interim Goals:

- Build industry experience supporting human missions with 3GPP (5G)
- Build NASA confidence in 5G for mission-critical applications
- Motivate the lunar 5G spectrum push
- Build the Artemis V feature set

Artemis Base Camp (multi-tower)



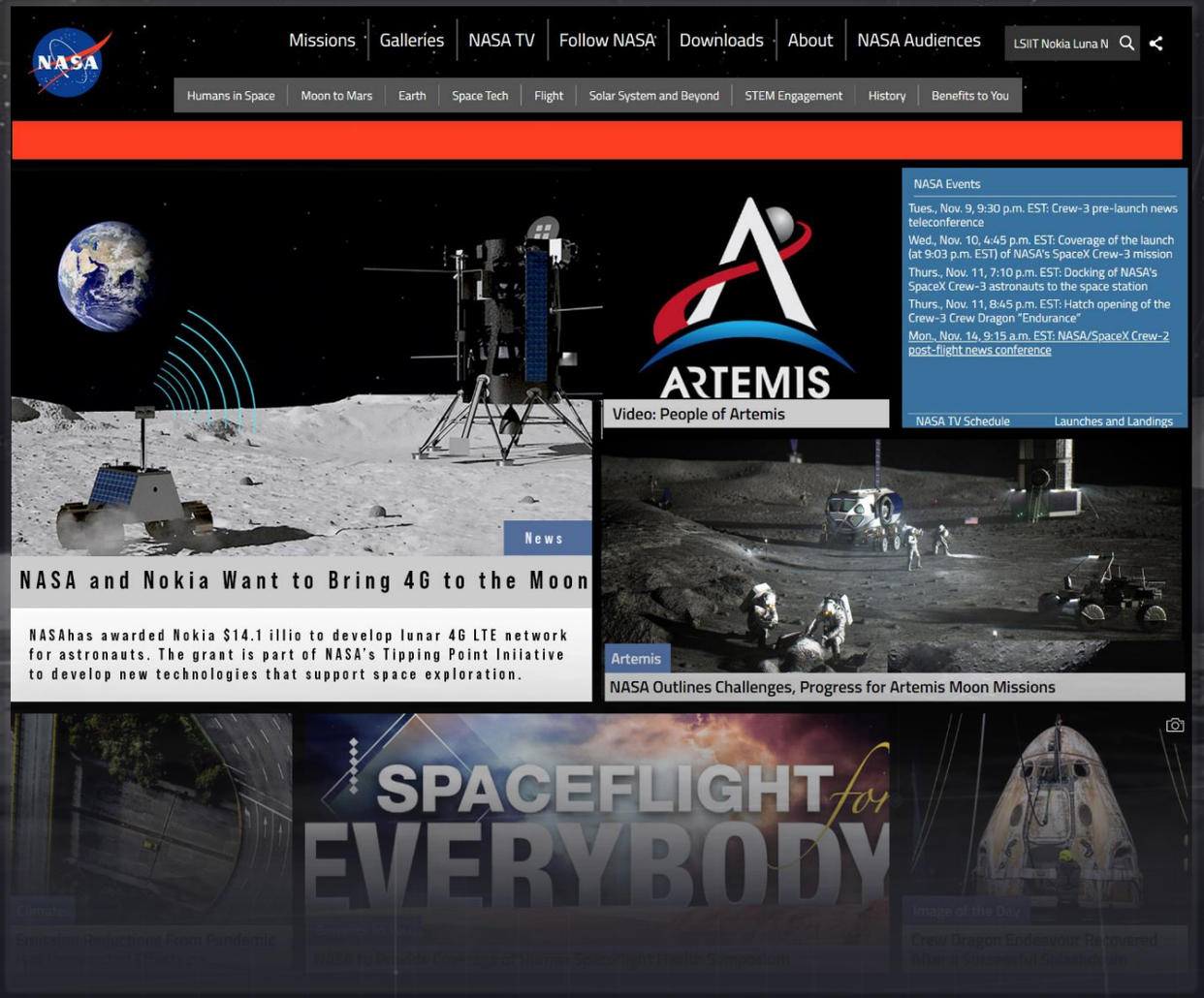
Artemis V Surface Network

- Human-rated, mission critical
- Single-tower
- (Likely) Multi-band
- Updated 3GPP release (5G)

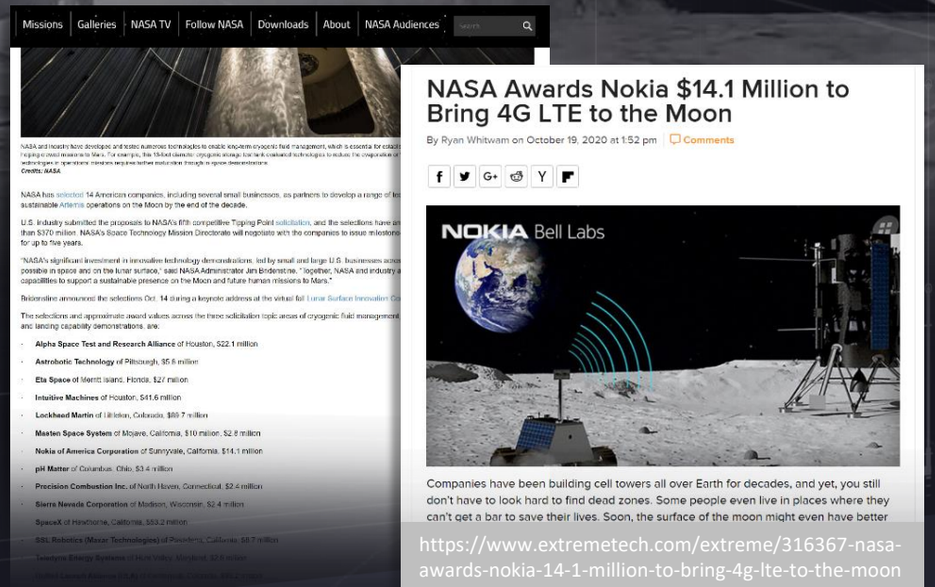
2023 — **2027**

3GPP as “Super Wi-Fi” → 3GPP as “phone company” →

What Could Commercial Service at the Moon Look Like?



- Bringing near-Earth commercial capability to the lunar environment
- Lunar surface use cases are analogous to terrestrial use cases that are supported by 3GPP (5G) Cellular Standards
- First steps… NASA awarded a Lunar Surface Innovation Initiative Technology Demonstration to Nokia, partnering with Intuitive Machines to demonstrate a 4G/LTE base station and user radio on the moon



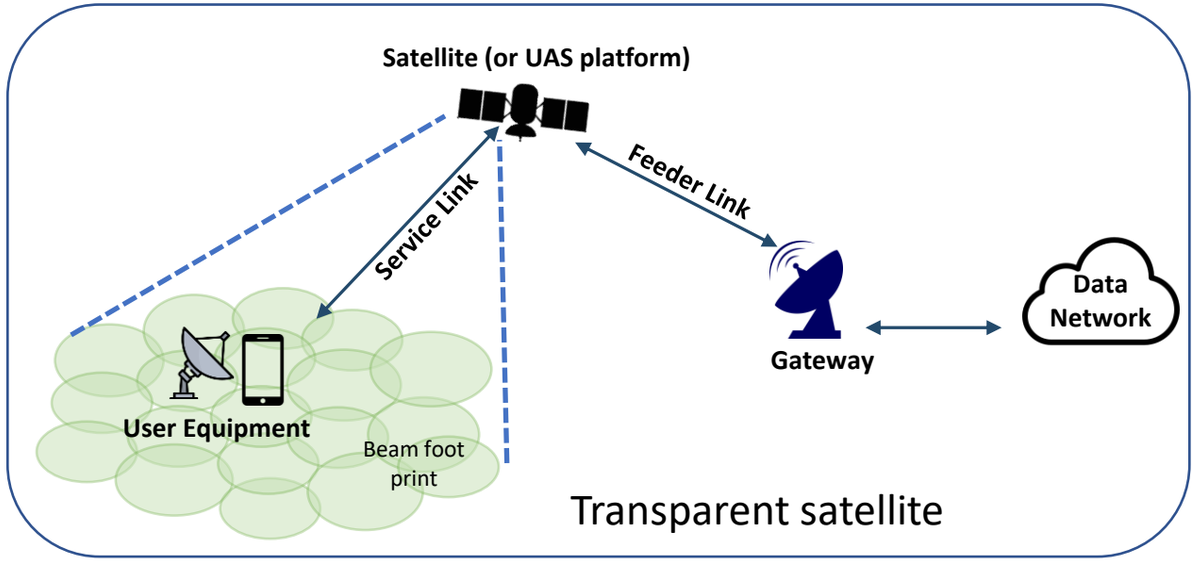
https://www.extremetech.com/extreme/316367-nasa-awards-nokia-14-1-million-to-bring-4g-lte-to-the-moon

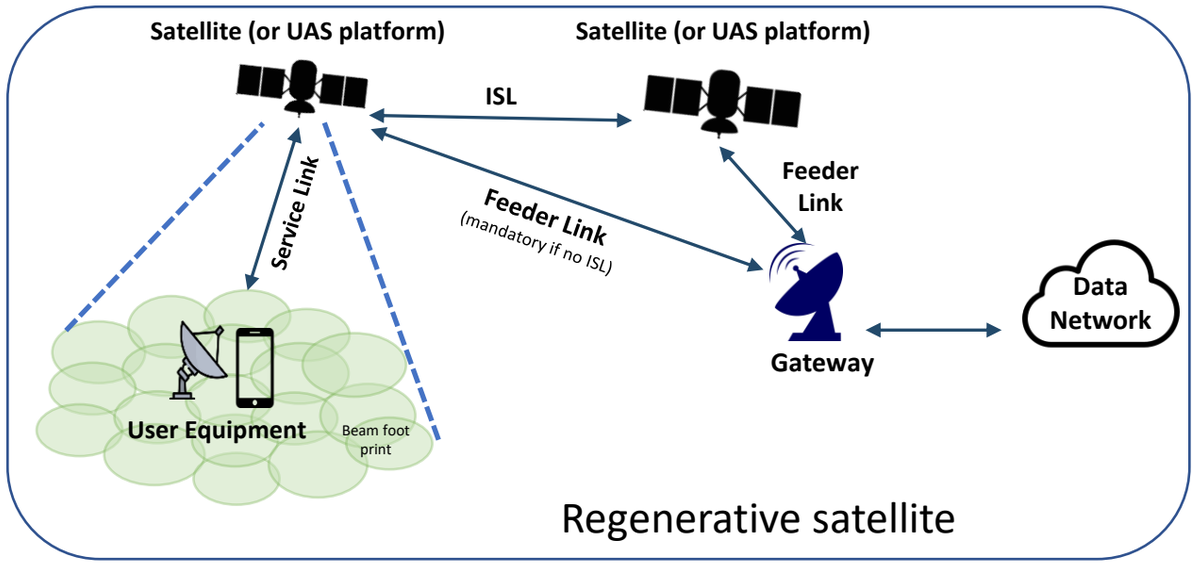
BACKUP

3GPP Non-Terrestrial Networks (NTN)

- **NASA understands there are ongoing NTN case studies to support connectivity to remote/ underserved regions:**
  - Transparent satellite
    - Core network and eNB on Earth
      - Satellite acts as a bent pipe to/from UEs located on Earth
  - Regenerative satellite
    - Core network and UEs on Earth, eNB on the satellite
  - Regenerative Satellite with inter-satellite link
    - Core network on Earth, eNBs in satellites, UEs on Earth
- **Replace Earth with lunar and these architectures are all useful to augment comms on the lunar surface.**
  - However, NASA is also interested in the idea of UEs in orbit

NASA is not aware of any organization considering the use case where UEs reside on a satellite





Satellite Based User Equipment (UE)

Potential applications:

- Scientific experiments in orbit
- Proximity communications with EVA astronauts in orbit
- Proximity communications for formation flying spacecraft
- Monitoring of space based autonomous systems

Satellite Based UEs share some technical challenges with official 3GPP NTN use cases, but there are also some unique challenges:

- Multi-user access
- Dynamic range and transmit power control
- Variation in round-trip delay
- Large Doppler

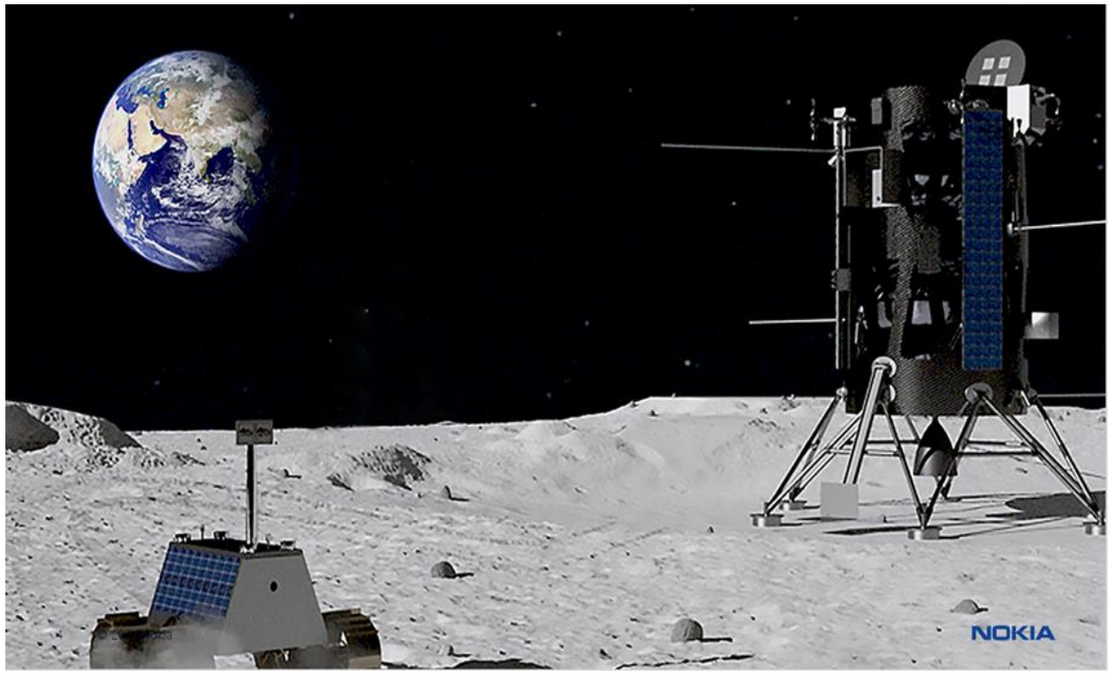
Nokia Lunar LTE Tipping Point Demonstration Objectives

To integrate Nokia's LTE/4G network assets onto Intuitive Machines' NOVA-C lander and a selected Lunar rover

To deploy equipment and establish a LTE/4G network on the surface of the Moon between the Lander and Rover

To verify the LTE/4G network performance in two main scenarios: for short-range (~100-300m) and for long-range (up to 2 km) surface communications (performance data sent to earth via the Lander)

The target launch date is 2023 and the Lunar mission duration is expected to last 12 days during lunar daylight



Post mission performance evaluation and scientific data is expected to enable TRL advancement of LTE Technology